Shared-Separation: Empirical Findings and Theoretical Implications

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Outline

- **Shared-separation: Empirical findings**
  - Air-Ground Integration Experiment (AGIE)
    - Project goals
    - Methods
    - Results
- **Shared-separation: Theoretical implications**
  - Hollnagel's Contextual Control Model
  - Proposed alternatives to shared-separation

Shared-Separation: Empirical Findings

AGIE Project Goals

- Identify operational issues that affect shared-separation operations
- Provide recommendations for information requirements and procedures
- Evaluate controller and pilot workload and situation awareness

AGIE Research Team & Sponsors

- **Real-time, human-in-the-loop simulation**
  - Completed in February 2000
- **Inter-Agency Working Group**
  - FAA HQ & FAA WJH Technical Center
  - NASA Ames Research Center
  - Volpe National Transportation Systems Center
- **Sponsors**
  - FAA (AAR-100, ASD-130, ATP-400)
  - NASA Ames Research Center (Advanced Air Transportation Technologies Program)

Facilities

- **FAA WJH Technical Center**
  - Interoperability and Integration Facility (I^2F)
    - Display System Replacement (DSR) workstations
  - User Request Evaluation Tool (URET)
- **NASA Ames Research Center**
  - Crew Vehicle System Research Facility (CVSRF)
    - Boeing 747-400 simulator
  - Cockpit Display of Traffic Information (CDTI) with airborne Alerting Logic (AL)

Experimental Design

- **4 Weeks of integrated simulation**
- **Participants**
  - 2 controller teams (R-side/D-side) each week
    - 3 weeks with Memphis ARTCC controllers
    - 1 week with Memphis ARTCC supervisors
  - 1 flight crew (pilot/co-pilot) each week
- **Memphis ARTCC airspace**
  - Sectors 21 & 44 (high-altitude)
- **Traffic scenarios**
  - 4, 90-minute scenarios

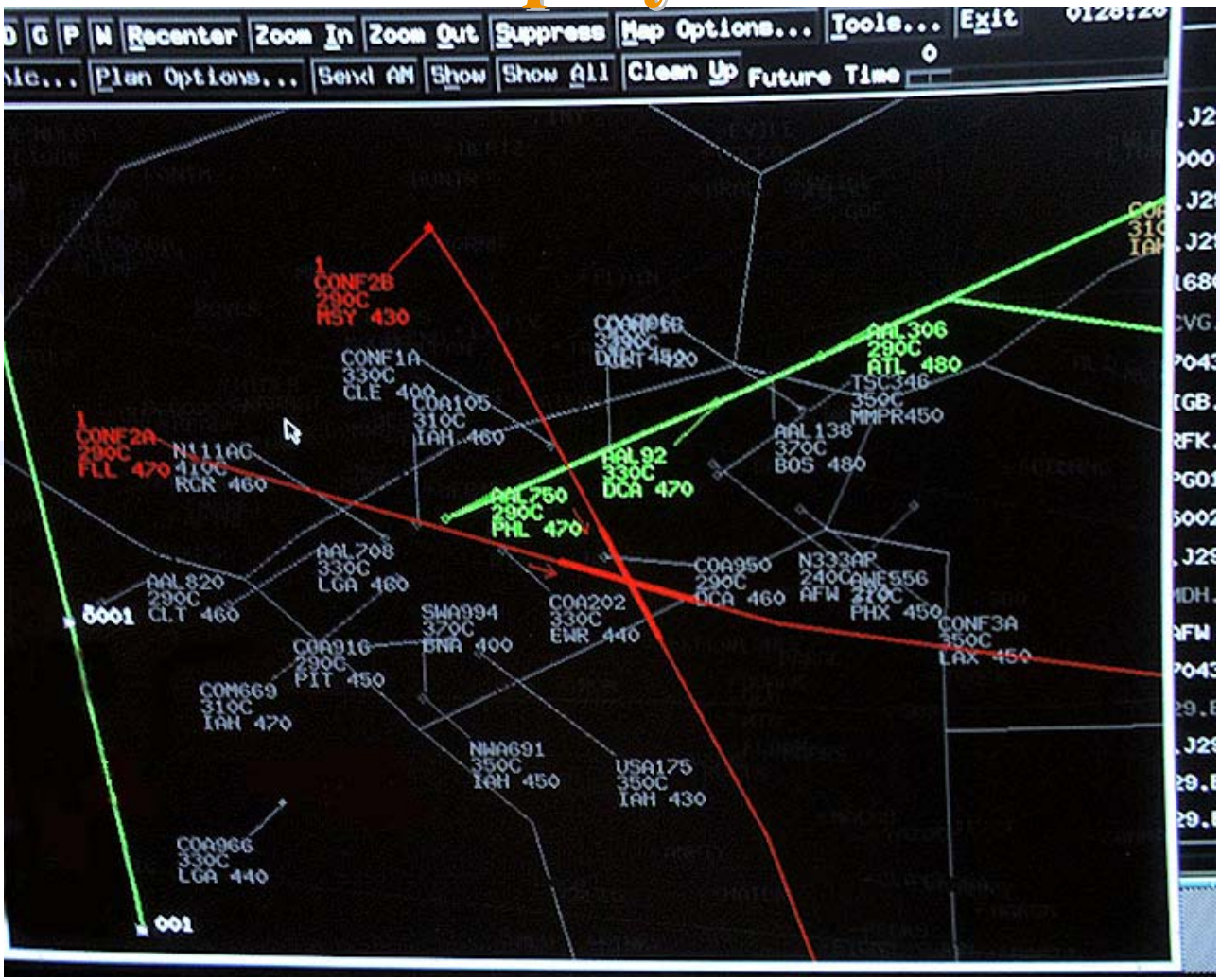
AGIE Experimental Conditions

- **Current Operations (CO)**
  - URET only
  - ATC full-separation environment
- **Current Operations with CDTI/AL (CO:CDTI)**
  - URET and CDTI/AL
  - ATC full-separation environment
- **Shared-Separation Level 1 (SS:L1)**
  - URET and CDTI/AL
  - ATC provided pilot intent information
- **Shared-Separation Level 2 (SS:L2)**
  - URET and CDTI/AL
  - ATC not provided pilot intent information

AGIE Scenarios

- **Traffic on controller's radar display**
  - DSR with URET
- **Traffic on flight deck (except for CO)**
  - CDTI (ADS-B range 120 nm)
- **Memphis ARTCC SAR-based scenarios**
- **Moderate to high traffic density, but low complexity**
- **Adjoining sectors to investigate operational issues pertaining to inter-sector coordination**
- **Air-to-air frequency (SS:L1 and SS:L2)**
- **16 planned conflicts per run involved two aircraft (only) converging at acute angles**

URET Display – Red Alert



AGIE Flight Deck Display (CDTI) Features

- **Available on the B747-400 navigation displays**
- **Assumes ADS-B range of 120 nm for surveillance**
- **Airborne alerting logic (velocity vector)**
- **TCAS II was also available to flight crews**
- **Altitude and airspeed displayed for all aircraft within range**
- **Navigation display range pilot selectable**
- **Callsign for aircraft pilot selectable**
- **Temporal predictors pilot selectable**
  - Displays prediction of aircraft location 1-10 minutes ahead

Flight Deck Display – Alert Status

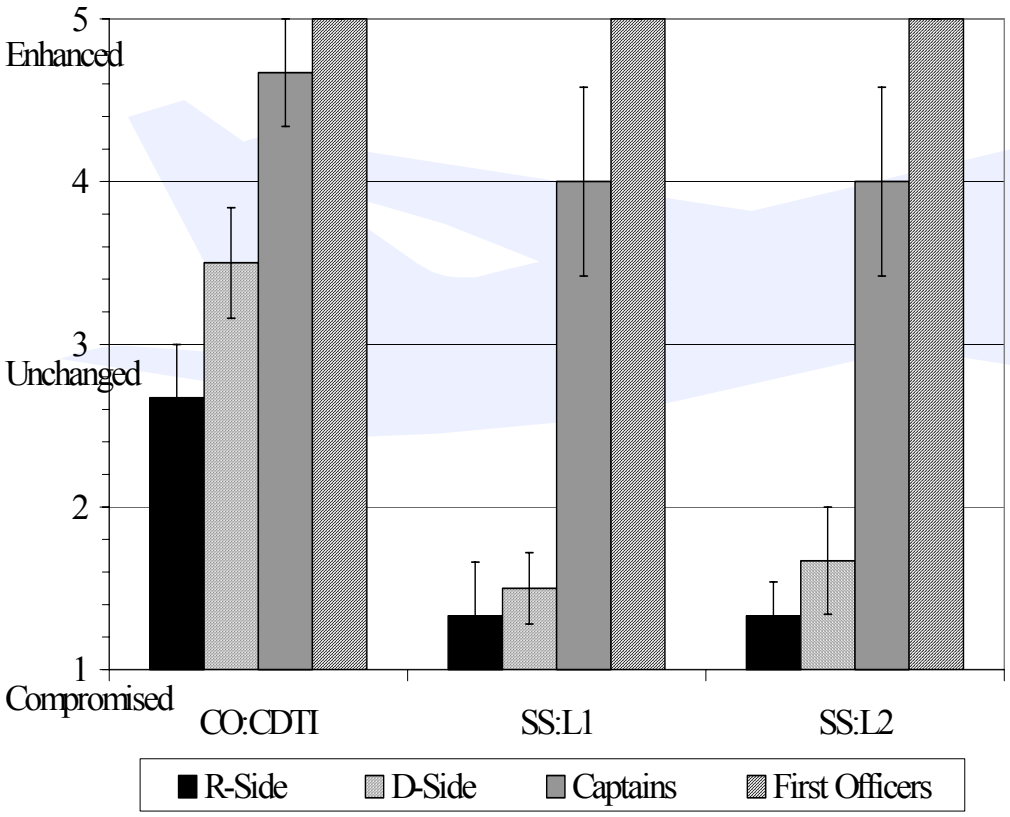
AGIE Results

Safety

- Pilots felt that safety was somewhat enhanced with the addition of the new technologies and shared-separation procedures
- Pilots felt that the CDTI/AL provided sufficient information in an adequate time to ensure safe operations
- Pilots did not violate minimum separation standards
- Controllers expressed concerns about the safety of the operational concept
- Controllers rated the time available for safe separation as slightly less in SS:L1 and SS:L2 compared to CO and CO:CDTI

Results (continued)

Safety



- **In SS:L2, Pilots did not feel safety was compromised despite increased task load**
- **Controllers rated the level of safety as lower in SS:L1 and SS:L2 compared to CO:CDTI (and CO)**
  - Tools did not compromise safety
  - Emphasized need for intent information

Results (continued)

Cancellation of Free Flight Operations

- **Pilots did not request any free flight cancellations**
- **Controllers tended to cancel free flight when they did not have pilot intent, air-to-air communications, and/or pilot's first maneuver**
  - For planned conflicts in SS:L1, controllers cancelled free flight 5 of 9 times (56%) for pilots, and 12 of 39 (31%) for simulation pilots.
  - Generally increased the magnitude of the flight crew's initial resolution strategy

Results (continued)

Conflict Resolution Strategies

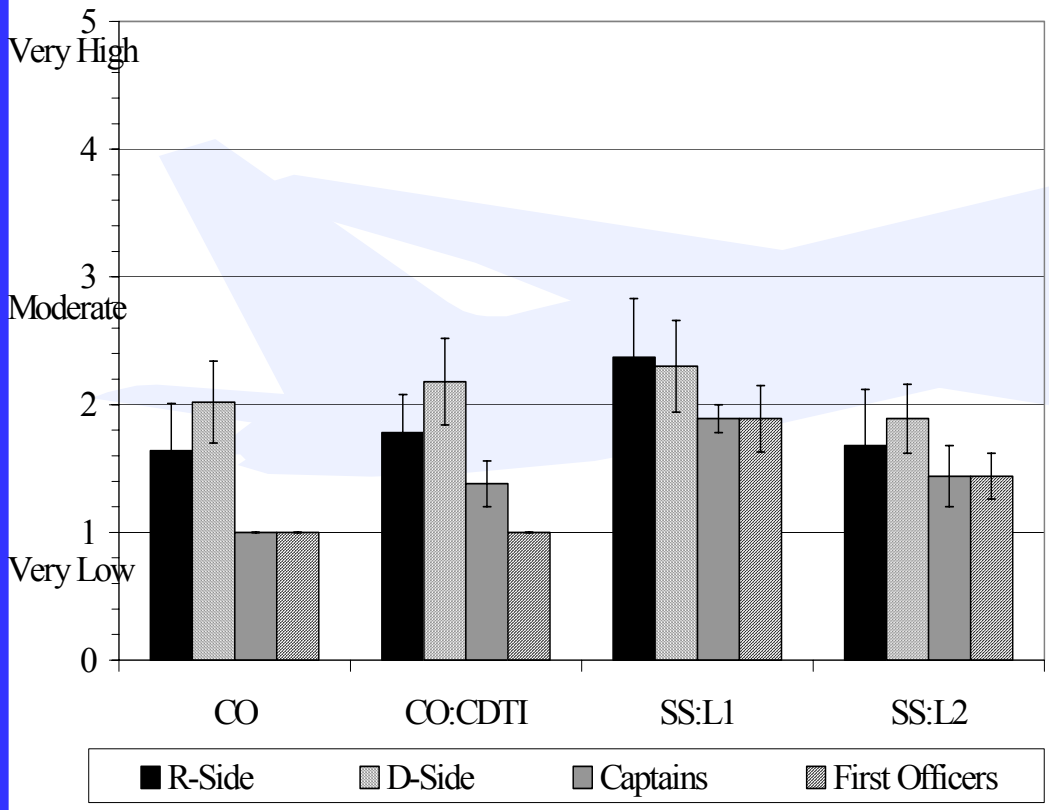
- Controllers indicated that they were uncomfortable with the resolution strategies being used by the pilots
- Both controllers and flight crews often used headings to resolve conflicts

Results (continued)

Conflict Resolution Strategies

- **Flight crews tended to initiate conflict resolution later than controllers and with multiple incremental maneuvers (minimizing impact on flight plan)**
  - Flight crews had more time to manage their own aircraft
  - Flight crews were able to use strategies that took more time to enact and monitor (speed, simultaneous speed and heading changes)
- **Controllers tended to resolve conflicts earlier and with a single maneuver**
  - "Fix and forget"; so they could continue to monitor other traffic

Results (continued)



Mean Ratings for Overall Workload

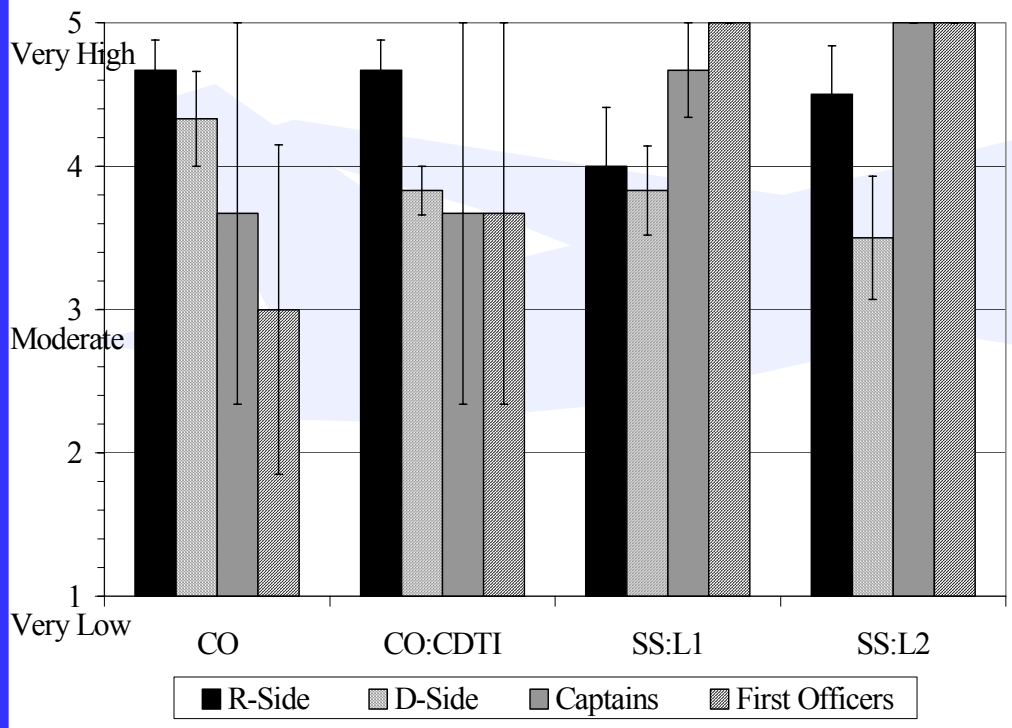
- **In general, *all* workload ratings were low**

Results (continued)

Workload

- **Flight crews *preferred* SS:L1 and particularly SS:L2,**
- **but… rated workload slightly higher in SS:L1 compared to CO & CO:CDTI**
- **and... *felt* SS:L1 was most workload intensive**
  - Increased display monitoring, communication, conflict detection and resolution tasks
  - SS:L1 also required additional workload to inform ATC of intent
- **Controllers *preferred* CO and CO:CDTI,**
- **but…rated workload similar for all conditions,**
- **and… *indicated* SS:L1 was the most work intensive and difficult condition**
  - Increased monitoring tasks, additional pilot resolution monitoring, continual contingency planning

Results (continued)



Mean Ratings for Overall Situation Awareness

- **Flight crews rated situation awareness higher for SS:L1 and SS:L2**
  - air-to-air frequency and CDTI/AL
- **Controllers rated their situation awareness as high for all conditions**

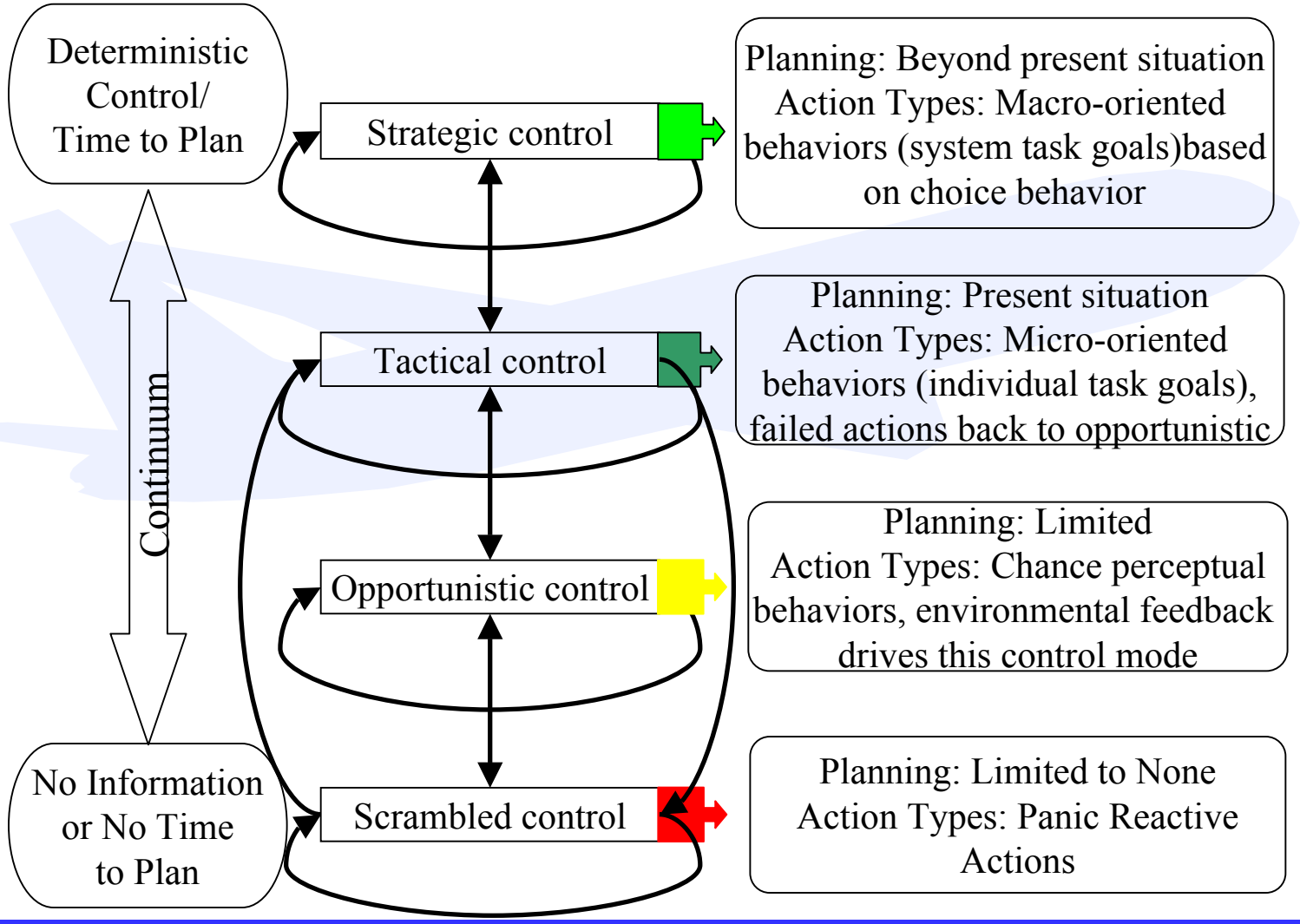
Shared-Separation: Theoretical Implications

Hollnagel's Approach

Contextual Control Model (COCOM)

- Human performance affected by situational context, and depends on
  - The subjectively available time to decide and act
  - The number of goals being considered
  - The feedback available on the effects of prior actions
  - The competency of the operator given the situation

COCOM Control Modes



Main Characteristics of the Control Modes

Control Mode	No. of goals	Subjectively available time	Choice of next action	Evaluation of outcome
Strategic	several	adequate	prediction based	elaborate
Tactical	few	adequate	plan based	normal
Opportunistic	one or two	just adequate	association based	primary effect
Scrambled	one	inadequate	random	rudimentary

Control Mode Changes

Mode changes occur when

- An unexpected event happens (towards scrambled)
- The operator accidentally takes the wrong action (towards scrambled)
- The operator's model of the system is in error and his/her actions do not have the desired effect (towards scrambled)
- The operator's actions prove effective and he/she can "get ahead" of the system (towards strategic)

COCOM modes and Pilot/ATC Performance

Controllers and pilots normally prefer strategic and/or tactical modes

- Want to plan ahead to achieve goals optimally
- Prefer more predictability
- Prefer more time for considering options
- Want feedback on prior actions

COCOM and ATM Research Findings

Verma and Corker (2001)

- Application of COCOM to model of controller performance and workload
- Found mismatch between control mode and operational procedures
  - Controllers attempting to apply tactical mode to free flight operations
- Mismatch led to higher computed workload

COCOM and ATM Research Findings (continued)

- **Corker et al. (2000) and AGIE have similar findings**
  - Apparent discomfort for controllers when separation responsibility is shared
    - Safety concerns
    - Cancellations of free flight
    - Workload higher in shared-separation
    - Concerns about intent uncertainty
- **AGIE findings, however, indicate pilots *preferred* shared-separation**
  - Situation awareness rating higher
  - Workload slightly higher (SS:L1), but still below “moderate”

Relationship between operational context and control modes

Conventional ATC without shift of separation authority

- Controllers able to operate closer to tactical/strategic modes
- Situation is predictable for controllers because they are in control
- Pilots react to controller instructions

Relationship between operational context and control modes in AGIE

- **Shared-separation (shift of separation authority)**
  - Controllers forced to "down" control continuum
  - Monitoring tasks with less direct control
  - Potential intervention required, but not predictable
  - Cannot manage workload or optimize their airspace
- **Pilots found shared-separation allowed for higher mode of control**
  - More direct control over conflict detection and resolution
  - Improved predictability and situation awareness
  - May allow more optimum trajectory for their aircraft

Possible solution: More direct ATC control

- **Hoffman et al. (2000) limited separation delegation**
  - Proposed in the Evolutionary Air-Ground Co-Operative Air Traffic Management Concepts Program
- **FAA/Eurocontrol AP-1 Principles of Operation of Airborne Separation Assurance Systems makes similar proposal**
- **Controller maintains task of problem identification and delegates resolution to pilot**
- **Pilot resolves conflicts, but within the bounds provided by controller (e.g., within time or maneuver constraints)**
- **May keep the controller in a more strategic mode**

Conclusions

- **There appear to be issues related to shared-separation**
  - Relevant to mixed equipage and transition between free flight and positive control
- **AGIE, other research efforts, and model implications identify need for further investigation**
  - What are the optimal roles for pilots and controllers in different kinds of airspace?
  - What tools and information are needed to support these roles?